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IUE OBSERVATIONS OF LUMINOUS BLUE STAR ASSOCIATIONS IN IRREGULAR GALAXIES

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ABSTRACT

Two regions of recent star formation in blue irregular galaxies have been observed with the IUE in the short wavelength, low dispersion mode. The spectra indicate that the massive star content is similar in these regions and is best fit by massive stars formed in a burst and now approximately 2.5-3.0 x10^6 years old.

1. INTRODUCTION

Irregular galaxies offer a special opportunity for the study of massive star formation. They are the bluest of galaxies, as a class, and this, together with the optical emission line spectra observed for some, indicates that massive stars are currently being formed. We are particularly interested in exploring the high mass end of the initial mass function (IMF) and the spatial patterns of star formation for the massive stars in these systems.

The irregular galaxies span a considerable range in morphology. The majority are blue, clumpy Im (Magellanic type) galaxies which have very obvious HII regions and associated OB associations. The remaining irregulars are classified I0 or Irr II, some of which are red, like M82. An interesting subset of the latter class are the Amorphous galaxies, which were first classified by Sandage and Brucato (1979). These Amorphous systems can be as blue or bluer than Im galaxies, but OB associations are not resolved, despite the relative proximity of the galaxies to us. Extensive HII regions are observed in these systems, however.

Ultraviolet spectra provide a means of exploring the hot stellar content of these galaxies. In a previous paper (Lamb et al. 1985) we investigated the massive star content of two amorphous irregulars - NGC 1705 and NGC 1800, through IUE (International Ultraviolet Explorer Satellite) observations, together with optical spectra. In this paper we continue the exploration of irregular galaxies through IUE ultraviolet spectra of two systems which have very different star-forming patterns: 1) NGC 1140 is a typical Amorphous system. It contains a large blob of ionized gas at its center upon which the IUE aperture was placed. 2) NGC 4449 is a classical, well-resolved Magellanic Irr with many star-forming

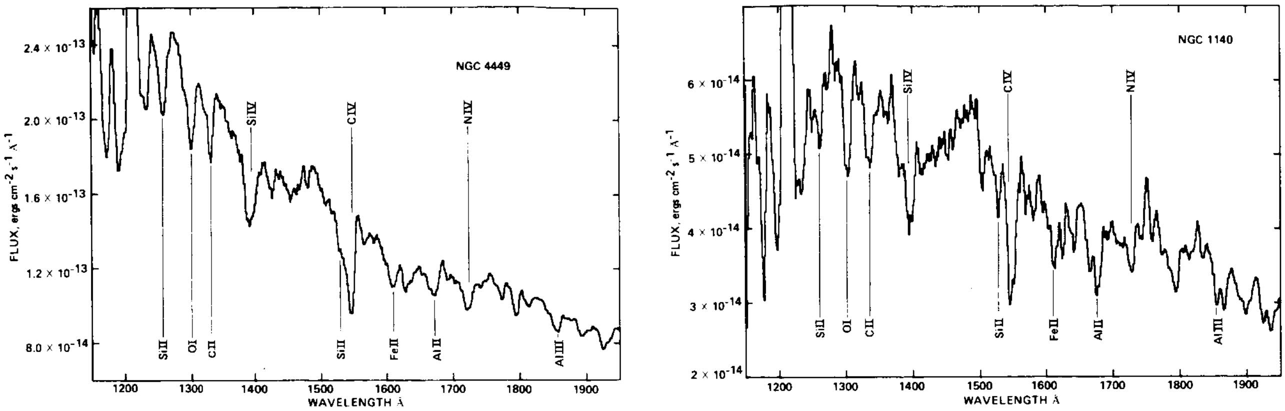

Fig. 1. IUE short wavelength spectra of NGC 4449 and NGC 1140. The two spectra of NGC 1140 were summed with a weighting proportional to their signal-to-noise. The spectrum for each galaxy was smoothed with a 5-point smoothing function. Lines of primarily stellar origin are identified above the spectra.

HII regions. One large HII region at the southwest end of the bar is in the form of an arc with a cluster of stars nestled in this arc (see Hunter and Gallagher 1985) and the IUE aperture was centered on this cluster.

Short-wavelength ultraviolet spectra were obtained at low-dispersion of these two galaxies in 1984 June and December. Setting with the 10"x20" aperture was by blind offset from bright stars. SWP 23262 of NGC 4449 is a 210 minute exposure, and SWP 24623 and SWP 24624 of NGC 1140 are respectively 180 and 185 minute exposures.

Data reductions and analysis were done using the Goddard Space Flight Center Regional Data Analaysis Facility. The results are shown in Figure 1, and we see that the primary stellar lines present are Si IV λ 1394, 1403Å, C IV λ 1548, 1551Å and N IV λ 1720Å. The other prominent absorption features arise from interstellar sources within the external galaxies, and there can be a substantial but unknown contribution from the interstellar medium of our own galaxy.

2. THE MASSIVE STAR CONTENT

2.1 Fitting the Ultraviolet Spectra

We have chosen to fit the overall shapes of the spectral lines, including P Cygni profiles when they are present, and to give considerable weight to the ratio of the equivalent widths of the SiIV and CIV features. This latter has been shown by Walborn and Panek (1984 a,b) to be a sensitive indicator of whether an individual massive star is on the main sequence or evolved into a supergiant. They have also demonstrated that the presence of SiIV P Cygni profiles is another indication of the luminosity class, as these develop only as the massive stars move off the main sequence.

We have constructed spectra of stellar clusters using the IUE stellar atlas (Wu et al. 1983) and relative contributions of stellar groups based on a standard

Salpeter (1955) initial mass function. The weighting factor is a product of the star's relative luminosity, number (the initial mass function), and lifetime (for evolved models). The relative luminosity at λ 1400-1500Å for a star was determined from the ratio of LF_λ (1400-1500Å) to T_e^4, where F_λ was determined from Kurucz (1979) model stellar atmospheres ($Z=Z_\odot$, log g=4). The relationship between T_e and stellar spectral class, mass and luminosity were obtained from Humphreys and McElroy (1984, see their Fig. 1), and the lifetimes of the stars were taken from models by Maeder (1981, 1983). Six stellar masses (9,15,30,60,85,120 $M_\odot$) were chosen as representative of six stellar groups, and average main sequence and evolved properties were determined for them. The atlas stellar spectra were extracted as point sources, corrected for reddening, and normalized to ~1500Å.

In constructing the synthesised models we attempted to span reasonable possibilities in the upper mass cut-off and the time dependence of the star formation rate. We did not vary the IMF, but our results are such that we can exclude a very flat IMF for the most massive stars. We constructed nine models. These included single burst models which varied from all main sequence stars to a burst now 3×10^6 years old, and extended production models in which the massive stars are either constantly formed or in which the production rate has fallen off by a factor of five from a maximum 3×10^6 years ago.

The best fit to our spectra of NGC 4449 and NGC 1140 were obtained from synthesised spectra of single bursts of star formation. The burst of age ~2.5 x 10^6 years with an upper mass cut off of ~120$M_\odot$ gave an equally good fit to that of the single burst of age ~3.0 x 10^6 years with an upper mass cut off of ~70-80 $M_\odot$. The main features needed to provide a good fit are plenty of massive supergiants and a lack of the most massive ($M>50M_\odot$) main sequence O stars. The emission hump in the spectra of NGC 1140 at λ 1400-1500Å was not fit by our synthesised spectra. This feature is due to Wolf Rayet stars (see Nussbaumer et al. 1982). Their spectra are not available in the IUE spectral atlas and are not included in our models.

2.2 Comparison with Spectra of Giant HII Regions.

Rosa et al. (1984) have published IUE spectra for a variety of extragalactic HII regions and we compare these to our spectra. The majority of the systems have quite similar short-wavelength spectra. That is, most giant extragalactic HII regions have spectra which are similar to those of late O, early B stars. A few systems have weaker stellar absorption features without having the strong emission lines of very hot stars, and a few systems are of higher excitation, having NIV] λ 1483,1486 Å emission (These latter systems include NGC 1140.)

Thus we conclude, from the similarity between our results and those for extragalactic HII regions, that the OB star population is roughly comparable in these systems. Small variations observed in these spectra indicate varying mixes of evolved massive stars which can most easily be attributed to an age spread from ~2.5 x 10^6 years to 10^7 years amoung the various regions.

In addition to the stellar features the energy distributions, i.e. the slopes of the continua, are all roughly similar for the giant HII regions and for our Amorphous galaxies. The similarities in the ultraviolet continua are actually quite remarkable. One might expect that dust contents and distributions would vary greatly from region to region and with time within a given region. We conclude that dust does not play a large role in those parts of the galaxies which we are observing in the ultraviolet.

3. THE SPATIAL PATTERNS OF STAR FORMATION.

Among the five Irr galaxies we have investigated (the two discussed here, plus NGC 1705, NGC 1800 and DDO 50, see Lamb et al. 1985 and Lamb et al. 1986), none are resolved into multiple clumps in the ultraviolet. Two of these galaxies, NGC 4449 and DDO 50, are Im type and do have a clumpy appearance in the optical. Although unresolved into clumps, the ultraviolet sources are broader than a point source. Our other three galaxies (NGC 1140, NGC 1705 and NGC 1800) are of the blue Amorphous type. These galaxies are more distant than our Im galaxies (ranging from 8.7 Mpc to 30 Mpc), and the large aperture of the IUE covers a considerable fraction of the galaxy. In each case the aperture was centered on the optical center of the object and in each case the ultraviolet source was point like.

It appears that the ultraviolet spectra are dominated by the youngest and brightest regions within the star forming complexes in all these galaxies. The Amorphous systems appear to experience massive star production in very condensed regions but the population of massive stars is not obviously different from that in normal Magellanic type irregulars.

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